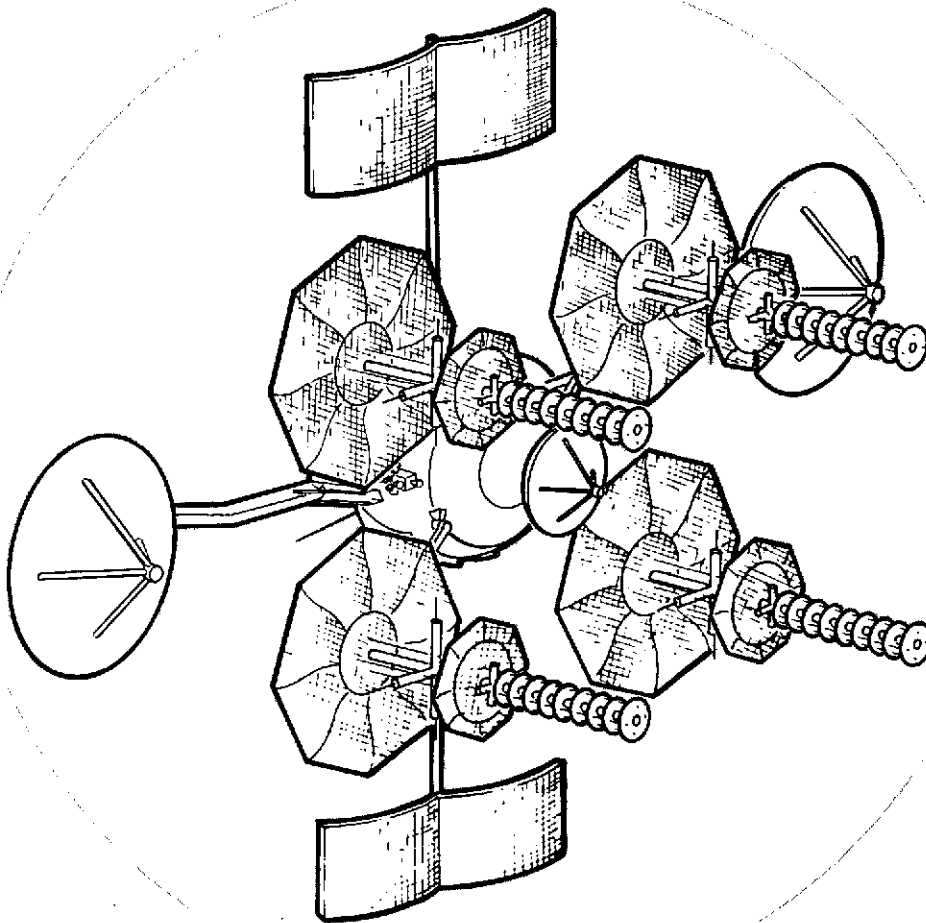


PART I FINAL REPORT

TRACKING & DATA RELAY SATELLITE SYSTEM CONFIGURATION & TRADEOFF STUDY

VOLUME VII TELECOMMUNICATIONS SYSTEM SUMMARY



OCTOBER 1972

SUBMITTED TO
GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION



Space Division
North American Rockwell

IN ACCORDANCE WITH
CONTRACT NAS5-21705

12214 Lakewood Boulevard, Downey, California 90241

N70-10811

NASA-CR-132841) TRACKING AND DATA RELAY
SATELLITE SYSTEM CONFIGURATION AND
TRADEOFF STUDY. VOLUME 7:
TELECOMMUNICATIONS SYSTEM (North American
Rockwell Corp.) 50-p HC \$4.50 CSCL 22B

Unclassified
G3/31 21943

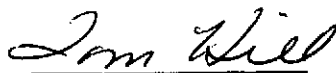
47



PART I FINAL REPORT

**TRACKING & DATA RELAY SATELLITE SYSTEM
CONFIGURATION & TRADEOFF STUDY**

**VOLUME VII
TELECOMMUNICATIONS SYSTEM SUMMARY**



T. E. Hill
TDRS STUDY MANAGER

OCTOBER 1972

SUBMITTED TO
GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION



Space Division
North American Rockwell

IN ACCORDANCE WITH
CONTRACT NAS5-21705

1 2 2 1 4 L a k e w o o d B o u l e v a r d D o w n e y C a l i f o r n i a 9 0 2 4 1

PRECEDING PAGE BLANK NOT ~~FILED~~

FOREWORD

This report summarizes the results of Part I of the study conducted under Contract NAS5-2107, Tracking and Data Relay Satellite Configuration and Systems Trade-off Study - 3-Axis Stabilized Configuration. The study was conducted by the Space Division of North American Rockwell Corporation for the Goddard Space Flight Center of the National Aeronautics and Space Administration.

The study is in two parts. Part I of the study considered all elements of the TDRS system but emphasized the design of a 3-axis stabilized satellite and a telecommunications system optimized for support of low and medium data rate user spacecraft constrained to be launched on a Delta 2914. Part II will emphasize upgrading the spacecraft design to provide telecommunications support to low and high, or low, medium and high data rate users, considering launches with the Atlas/Centaur and the Space Shuttle.

The report consists of the following seven volumes.

- | | |
|--|-----------------|
| 1. Summary | SD 72-SA-0133-1 |
| 2. System Engineering | SD 72-SA-0133-2 |
| 3. Telecommunications Service System | SD 72-SA-0133-3 |
| 4. Spacecraft and Subsystem Design | SD 72-SA-0133-4 |
| 5. User Impact and Ground Station Design | SD 72-SA-0133-5 |
| 6. Cost Estimates | SD 72-SA-0133-6 |
| 7. Telecommunications System Summary | SD 72-SA-0133-7 |

Acknowledgment is given to the following individuals for their participation in and contributions to the conduct of this study:

M.A. Cantor	North American Rockwell	System Engineering and Spacecraft Design
A.A. Nussberger	"	Electrical Power
W.C. Shmill	"	"
R.E. Oglevie	"	Stabilization and Control
A.F. Boyd	"	"
R.N. Yee	"	Propulsion
A.D. Nusenow	"	Thermal Control
T.F. Rudiger	"	Flight Mechanics
J.W. Collins	"	Satellite Design
P.H. Dirnbach	"	Reliability
W.F. Deutsch	"	Telecommunications Design
S.H. Turkel	"	Operations Analysis
A. Forster	"	Cost
A.F. Anderson	"	Integration
T.T. Noji	AIL-Division of Cutler-Hammer	Telecommunications Design
L. Swartz	"	"
D.M. DeVito	The Magnavox Company	Telecommunication System Analysis
D. Cartier	"	Ground Station Design
R.H. French	"	Operations Analysis
G. Shaushanian	"	User Transponder Design



PRECEDING PAGE BLANK NOT FILMED

TABLE OF CONTENTS

VOLUME I

Section	Page
1.0 SUMMARY	1-1
1.1 SYSTEM CONCEPT	1-3
1.2 SATELLITE LAUNCH AND DEPLOYMENT	1-7
1.2.1 Deployment Analysis	1-7
1.2.2 Launch Analysis	1-8
1.2.3 Launch and Deployment Profile	1-11
1.3 TELECOMMUNICATIONS DESIGN	1-13
1.3.1 Telecommunications System Analysis	1-13
1.3.2 Telecommunications Subsystem Design	1-25
1.3.3 Telecommunications Relay Performance	1-29
1.4 SPACECRAFT MECHANICAL AND STRUCTURAL DESIGN	1-35
1.5 ELECTRICAL POWER SUBSYSTEM	1-51
1.6 ATTITUDE STABILIZATION AND CONTROL SUBSYSTEM	1-54
1.7 AUXILIARY PROPULSION SUBSYSTEM	1-57
1.7.1 Reaction Control Subsystem	1-57
1.7.2 Apogee Motor	1-60
1.8 THERMAL CONTROL	1-60
1.9 RELIABILITY	1-64
1.10 USER TRANSPONDER DESIGN	1-66
1.10.1 LDR Transponder	1-66
1.10.2 MDR Transponder	1-66
1.11 NETWORK OPERATIONS AND CONTROL	1-68
1.12 TDRS GROUND STATION	1-77
1.13 RECOMMENDATIONS	1-82

VOLUME II

2.0 SYSTEM ENGINEERING	2-1
2.1 MISSION ANALYSIS	2-1
2.1.1 Network Configuration	2-1
2.1.2 TDRS Operational Plan	2-6
2.1.3 Performance Sensitivity	2-19
2.1.4 TDRS On-Orbit Payload Capability	2-21
2.1.5 Launch and Deployment Profile	2-22
2.1.6 Launch and Deployment Timeline	2-27
2.2 NETWORK OPERATIONS AND CONTROL	2-33
2.2.1 TDRS System Concept	2-33
2.2.2 Primary System Elements and Their Operational and Functional Interfaces	2-37
2.2.3 TDRSS Functional Analysis	2-48
2.2.4 TDRS Operational Phase Sequence of Events	2-113
2.3 SYSTEM RELIABILITY ANALYSIS	2-139

VOLUME III

Section	Page
3.0 TELECOMMUNICATIONS SYSTEM ANALYSIS	3-1
3.1 RELAY SYSTEM REQUIREMENTS AND CONSTRAINTS	3-1
3.1.1 Design Goals	3-1
3.1.2 System Design Criteria	3-1
3.1.3 Telecommunication System Description	3-3
3.2 THE INTERFERENCE PROBLEM	3-4
3.2.1 Radio Frequency Interference	3-6
3.2.2 "Trash Noise" and Its Effect on the TDRS Channels	3-11
3.2.3 The TDRS User Propagation Path	3-16
3.3 FREQUENCY SELECTION	3-21
3.3.1 Frequency Trades	3-21
3.3.2 Frequency Plan	3-25
3.4 MODULATION AND CODING	3-25
3.4.1 Impact of Forward Error Control on the Medium and Low Data Rate Users	3-25
3.4.2 Voice Coding for Manned Users of the Tracking and Data Relay Satellite System	3-32
3.5 RELAY SYSTEM PERFORMANCE ANALYSIS	3-37
3.5.1 Forward (Command) Link Communications Performance	3-39
3.5.2 Return (Telemetry) Link Communications Performance	3-44
3.5.3 TDRS Tracking Performance	3-51
3.5.4 Pseudo-Random Code Acquisition and Tracking	3-67
3.5.5 Manned User Performance	3-76
3.6 REFERENCES	
4.0 TDRS TELECOMMUNICATION SUBSYSTEM	4-1
4.1 TELECOMMUNICATION SYSTEM REQUIREMENTS	4-7
4.1.1 Design Goals and Criteria	4-7
4.1.2 Requirements and Constraints	4-10
4.2 TELECOMMUNICATION SYSTEM DESIGN DESCRIPTION	4-12
4.2.1 Frequency Plan	4-12
4.2.2 Functional Description	4-22
4.2.3 Telecommunications Subsystem Size, Weight, and Power Summary	4-30
4.3 LOW DATA RATE LINK	4-32
4.3.1 Return Link	4-32
4.3.2 LDR Antenna	4-61
4.3.3 LDR Transponder	4-68



Section	Page
4.3.4	Performance Specification for LDR Transponder 4-81
4.3.5	Size, Weight, and Power Summary for LDR Transponder 4-86
4.4	MEDIUM DATA RATE LINK 4-87
4.4.1	MDR System Analysis and Trades 4-87
4.4.2	MDR Antennas 4-95
4.4.3	MDR Transceiver 4-100
4.4.4	Performance Specification for MDR Transponder 4-110
4.5	TDRS/GS LINK 4-119
4.5.1	System Analysis and Trades 4-119
4.5.2	TDRS/GS Link Antenna 4-124
4.5.3	TDRS/GS Transceiver 4-128
4.5.4	Performance Specification for the TDRS/GS Link Transponder 4-146
4.5.5	Size, Weight, and Power Summary of TDRS/GS Link Transponder 4-150
4.6	FREQUENCY SOURCE 4-151
4.6.1	System Analysis and Tradeoffs 4-151
4.6.2	Detailed Description of the Frequency Source 4-153
4.6.3	Performance Specification for the TDRS Frequency Source 4-157
4.6.4	Size, Weight, and Power Summary for TDRS Frequency Source 4-161
4.7	TRACKING, TELEMETRY, AND COMMAND SYSTEM 4-162
4.7.1	Mechanization Trades 4-163
4.7.2	Detailed Description of TT&C Transponder 4-163
4.7.3	Performance Specification for the TDRS Tracking, Telemetry and Command Subsystem 4-170
4.7.4	Size, Weight, and Power Summary for TT&C 4-172
4.8	TDRS TRACKING/ORDER WIRE TRANSPONDER 4-173
4.8.1	System Analysis and Trades 4-173
4.8.2	Detailed Description of TDRS Tracking Order Wire 4-175
4.8.3	Performance Specification for TDRS Tracking/Order Wire Transponder 4-177
4.8.4	Size, Weight, and Power Summary for the TDRS Tracking/Order Wire Transponder 4-179
4.9	Ku-BAND BEACON 4-179
4.9.1	System Description 4-179
4.9.2	Performance Specification of the Ku-Band Beacon 4-181
4.9.3	Size, Weight, and Power Summary of the Ku-Band Beacon 4-181



VOLUME IV

Section		Page
5.0	SPACECRAFT MECHANICAL AND STRUCTURAL DESIGN . . .	5-1
5.1	TDRS BASELINE CONFIGURATION . . .	5-2
5.1.1	Deployed Configuration . . .	5-2
5.1.2	Launch Configuration . . .	5-2
5.2	SPACECRAFT BODY STRUCTURE . . .	5-6
5.3	ANTENNA MECHANICAL DESIGN . . .	5-9
5.3.1	MDR Antennas . . .	5-9
5.3.2	LDR UHF-VHF Array Structural Construction . . .	5-9
5.3.3	TDRS/GS Antenna . . .	5-10
5.3.4	TT&C Antennas . . .	5-10
5.3.5	Ku- and S-Band Tracking/Order Wire Antennas . . .	5-13
5.4	SOLAR ARRAY PANELS AND DRIVE MECHANISM . . .	5-13
5.4.1	Solar Panels . . .	5-13
5.4.2	Drive Mechanism . . .	5-14
5.5	SUBSYSTEMS INSTALLATION . . .	5-14
5.6	ACCESSIBILITY AND SERVICING PROVISIONS . . .	5-21
5.7	MASS PROPERTIES . . .	5-21
5.8	SUBSYSTEM INTEGRATION . . .	5-21
6.0	ATTITUDE STABILIZATION AND CONTROL SUBSYSTEM (ASCS) . . .	6-1
6.1	PERFORMANCE REQUIREMENTS . . .	6-1
6.2	DISTURBANCE TORQUES AND MOMENTUM STORAGE REQUIREMENTS . . .	6-3
6.2.1	Solar Pressure Torques . . .	6-3
6.2.2	Antenna Gimbaling Disturbances . . .	6-8
6.2.3	Momentum Storage Requirements . . .	6-8
6.3	SYSTEM MECHANIZATION TRADE STUDIES . . .	6-13
6.3.1	Transfer Orbit and Deployment Phase . . .	6-13
6.3.2	On-Orbit Phase Torquer and Momentum Storage Subsystem Trades . . .	6-15
6.3.3	Attitude Determination Sensor Trades . . .	6-22
6.4	BASELINE SYSTEM DESCRIPTION . . .	6-25
6.4.1	Spin Stabilized Control Mode . . .	6-25
6.4.2	Three-Axis Stabilized Control System . . .	6-30
6.5	APS Performance Requirements . . .	6-33
6.5.1	Propellant Requirements . . .	6-33
6.5.2	Thruster Performance Requirements . . .	6-36
6.5.3	Reaction Jet Configuration . . .	6-39

Section		Page
7.0	PROPULSION SYSTEM	7-1
	7-1 APS REQUIREMENTS AND CRITERIA	7-1
	7-2 ANALYSIS AND TRADE STUDIES	7-2
	7-3 SUBSYSTEM DESIGN	7-7
	7.3.1 Description	7-7
	7.3.2 Performance	7-8
	7-4 DESIGN CONSIDERATIONS	7-16
	7.4.1 Operating Life	7-16
	7.4.2 Thrust Vector Alignment	7-17
	7.4.3 Performance Verification	7-17
	7-5 APOGEE MOTOR	7-17
8.0	ELECTRICAL POWER SUBSYSTEM (EPS)	8-1
	8.1 EPS SUMMARY	8-1
	8.1.1 Alternative Concepts	8-3
	8.1.2 Requirements	8-5
	8.1.3 EPS Description	8-13
	8.2 PRIMARY POWER GENERATION ASSEMBLY	8-15
	8.2.1 Solar Array Function and Description	8-15
	8.2.2 Solar Array Assembly Characteristics	8-18
	8.2.3 Operational Constraints and Growth Considerations	8-20
	8.3 ENERGY STORAGE ASSEMBLY	8-22
	8.3.1 Function and Description	8-22
	8.3.2 Assembly Characteristics	8-24
	8.3.3 Growth Considerations	8-26
	8.4 POWER CONDITIONING ASSEMBLY	8-26
	8.4.1 Function and Description	8-26
	8.4.2 Power Conditioning Assembly Characteristics	8-28
	8.4.3 Operational Constraints and Growth Considerations	8-30
	8.5 DISTRIBUTION, CONTROL AND WIRING ASSEMBLY.	8-31
	8.5.1 Function and Description	8-31
	8.5.2 Assembly Characteristics	8-31
	8.6 EFFECT OF BATTERY CAPABILITY OF TDRS VOICE TRANSMISSION	8-33
9.0	THERMAL CONTROL	9-1
	9.1 REQUIREMENTS	9-1
	9.1.1 Mission Requirements	9-1
	9.1.2 Heat Rejection Loads	9-1
	9.1.3 Temperature Limits	9-4
	9.1.4 Design Constraints and Problem Areas.	9-4



Section	Page
9.2 SYSTEM DESCRIPTION	9-7
9.2.1 Louver Radiator	9-7
9.2.2 Multilayer Insulation	9-10
9.2.3 Thermal Control Coatings	9-13
9.2.4 Equipment Component Placement	9-13
9.3 ALTERNATE CONCEPTS	9-15
9.3.1 Passive Design	9-15
9.3.2 Variable Conductance Heat Pipe Radiator	9-15
9.4 SUBSYSTEM THERMAL CONTROL	9-16
9.4.1 APS	9-16
9.4.2 Solar Array Panel	9-18
9.4.3 Antennas	9-22
9.4.4 Apogee Motor	9-22
9.4.5 Excess Power Dissipation	9-23
9.5 SYSTEM DEFINITION	9-23
10.0 RELIABILITY	10-1
10.1 DEFINITIONS	10-1
10.2 RELIABILITY GOALS AND CRITERIA	10-2
10.3 SUBSYSTEM ANALYSIS	10-5
10.3.1 Telecommunications	10-5
10.3.2 Structure and Mechanics	10-13
10.3.3 Attitude Control	10-13
10.3.4 Auxiliary Propulsion Subsystem (APS).	10-13
10.3.5 Electrical Power	10-15
10.3.6 Thermal Control	10-15
10.4 SINGLE FAILURE POINT SUMMARY	10-18
10.5 RELIABILITY PROGRAM FOR IMPLEMENTATION PHASE	10-24
VOLUME V	
11.0 USER SPACECRAFT IMPACT	11-1
11.1 USER SPACECRAFT TRANSPONDER CONCEPTS AND TRADES	11-1
11.1.1 LDR Transponder	11-1
11.1.2 MDR Transponder	11-5
11.2 USER SPACECRAFT TRANSPONDER MECHANIZATION	11-7
11.2.1 LDR Transponder	11-7
11.2.2 MDR Transponder	11-15
11.3 CONCLUSIONS	11-19
12.0 TDRS GROUND STATION DESIGN	12-1
12.1 REQUIREMENTS AND CONSTRAINTS	12-1
12.1.1 Uplink Requirements and Constraints	12-1
12.1.2 Downlink Requirements and Constraints	12-3

Section

	Page
12.2 TDRS GROUND STATION	12-4
12.2.1 TDRS GS Antenna Subsystem	12-4
12.2.2 Antenna Site Analysis	12-5
12.3 ANTENNA SITE ISOLATION ANALYSIS	12-6
12.4 Ku-BAND GROUND STATION ANTENNA	12-6
12.4.1 TDRS Ground Station Receiver Front End	12-8
12.4.2 TDRS Ground Station FM Demodulator and Demultiplexer.	12-8
12.4.3 TDRS Ground Station LDR Processing	12-9
12.4.4 TDRS Ground RF Transmitter	12-9
12.4.5 TDRS Ground Station FDM Multiplexing	12-9
12.4.6 TDRS Ground Station Frequency Source	12-10
12.4.7 TDRS Ground Link Backup Mode	12-10
12.5 DESIGN CONSIDERATIONS	12-11
12.5.1 Signal Categories	12-11
12.5.2 LDR Command/Tracking (Uplink).	12-11
12.5.3 LDR Telemetry	12-13
12.5.4 LDR/MDR Tracking (Downlink)	12-13
12.5.5 MDR Command (P/BU)/Uplink Voice (P/BU)/Tracking	12-13
12.5.6 MDR Telemetry (P/BU)	12-14
12.5.7 TDRS Order Wire	12-14
12.5.8 MDR Downlink Voice (P/BU) (Manned User)	12-17
12.5.9 TDRS Command/Tracking (P/BU)	12-17
12.5.10 TDRS Telemetry (P/BU)	12-17
12.5.11 TDRS Tracking (Downlink) (P/BU)	12-17
12.5.12 Ground Station/Network Communications	12-19
12.6 CONCEPT DESCRIPTION	12-19
12.6.1 LDR Command/Tracking (Uplink).	12-20
12.6.2 LDR Telemetry	12-20
12.6.3 LDR/MDR Tracking (Downlink)	12-21
12.6.4 MDR Command (P/BU)/Uplink Voice (P/BU) Tracking	12-21
12.6.5 MDR Telemetry (P/BU)	12-21
12.6.6 TDRS Order Wire	12-22
12.6.7 MDR Downlink Voice (P/BU) (Manned User)	12-22
12.6.8 TDRS Command/Tracking (P/BU)	12-22
12.6.9 TDRS Telemetry (P/BU)	12-23
12.6.10 TDRS Tracking (Downlink) (P/BU)	12-23
12.6.11 Ground Station/Network Communications	12-23
12.6.12 Demodulation Tracking Unit	12-23
12.6.13 Modulation Unit	12-25
12.6.14 Control and Monitor Subsystem.	12-26
12.7 CONCLUSIONS AND RECOMMENDATIONS	12-31

VOLUME VI

Section		Page
13.0	COSTING	13-1
13.1	INTRODUCTION.	13-1
	13.1.1 Cost Analysis	13-1
	13.1.2 TDRSS Program Cost Estimates.	13-1
13.2	TDRSS BASELINE DESCRIPTION	13-3
	13.2.1 TDRSS Operational Concept	13-3
	13.2.2 TDRS Design Concept	13-5
	13.2.3 TDRS Technical Characteristics	13-5
13.3	TDRSS COSTING REQUIREMENTS	13-5
	13.3.1 Costing Ground Rules	13-5
	13.3.2 Costing Work Breakdown Structure	13-9
	13.3.3 Schedules	13-10
13.4	SPACECRAFT COST ANALYSIS.	13-14
	13.4.1 Cost Methodology.	13-14
	13.4.2 Alternate Cost Models Description	13-15
	13.4.3 TDRS Cost Estimates Based on Alternate Cost Models	13-17
	13.4.4 Selected TDRS Cost Models	13-19
	GLOSSARY	13-25
	APPENDIX 13A. SAMSO/NR NORMALIZED COST MODEL	13A-1

VOLUME VII

14.0	TELECOMMUNICATIONS SYSTEM SUMMARY	14-1
14.1	INTRODUCTION	14-1
14.2	SYSTEM SERVICE AND PERFORMANCE SUMMARY	14-4
	14.2.1 LDR Return Link	14-4
	14.2.2 LDR Forward Link.	14-6
	14.2.3 MDR Link Performance	14-8



Section		Page
14.3	LINK BUDGET	14-12
14.3.1	LDR Return Link Budget	14-12
14.3.2	LDR Forward Link Budget.	14-14
14.3.3	MDR Return Link Budget	14-14
14.3.4	MDR Forward Link Budget.	14-17
14.3.5	TDRS/GS Return Link Budget	14-17
14.3.6	TDRS/GS Forward Link Budget	14-20
14.3.7	Tracking/Order Wire	14-24
14.3.8	Ku-Band Beacon	14-24
14.4	SUBSYSTEM TERMINAL CHARACTERISTICS	14-24
14.4.1	TDRS Telecommunication Subsystem	14-24
14.4.2	User Transponder Design.	14-26
14.4.3	Ground Station Terminal Characteristics	14-33

ILLUSTRATIONS

Figure		Page
14-1	Components of the TDRS Telecommunication System	14-1
14-2	LDR Return Link Performance Achievable Bit Rate, Range Error, and Range Rate Error	14-5
14-3	LDR Forward Link Performance Achievable Data Rate; Range Error and Range Rate Error.	14-7
14-4	MDR Return Link Performance	14-7
14-5	MDR Forward Link Performance	14-10
14-6	System Noise Temperature Vs Noise Temperature of Parametric Amplifier	14-19
14-7	CNR Calculation in TDRS/GS Forward Link	14-22
14-8	Telecommunications Subsystem Block Diagram	14-27
14-9	LDR Transponder	14-31
14-10	MDR Transponder	14-31
14-11	Ground Station.	14-35

TABLES

Table		Page
14-1	Telecommunications Service Requirements	14-2
14-2	System Frequency Plan	14-3
14-3	LDR - Return Link Budget	14-13
14-4	LDR - Forward Link Budget at UHF	14-15
14-5	MDR Return Link Budget (S-Band)	14-16
14-6	MDR Return Link Budget (Ku-Band)	14-16
14-7	MDR Forward Link Budget	14-18
14-8	TDRS-to-Ground Station Return Link Budget	14-21
14-9	Ground Station-to-TDRS Forward Link Budget	14-23
14-10	TDRS Tracking/Order Wire Transponder and Ku-Band Beacon Link Budgets	14-25
14-11	Telecommunication Transponder Characteristics	14-29
14-12	Telecommunication Subsystem Size, Weight, and Power Summary	14-30
14-13	Ground Station Telecommunications Characteristics	14-34

14.0 SUMMARY OF THE TDRS TELECOMMUNICATION SYSTEM

14.1 INTRODUCTION

This volume summarizes the baseline TDRSS Telecommunication System including the TDR Satellite Telecommunication Subsystem, User Spacecraft Terminal, and the Ground Based Terminal as illustrated in Figure 14-1. Detailed analysis and description of the Telecommunication Subsystem is included in Volume III, and User Spacecraft Impact and the Ground Station are combined in Volume V of this Part I Final Report. The topics covered are:

- System Service and Performance Summary showing the link support, modes of operation, and link performance to the Low Data Rate and Medium Data Rate User Spacecraft.
- Link Budget Calculation to show a typical computation for each space-to-space and space-to-ground link including the assumptions used in each calculation.
- Summary of subsystem terminal characteristics including the Spaceborne Telecommunication System, User Spacecraft Terminal, and Ground Station.

The overall telecommunications service requirements are shown in Table 14-1, and the overall working frequency plan is shown in Table 14-2.

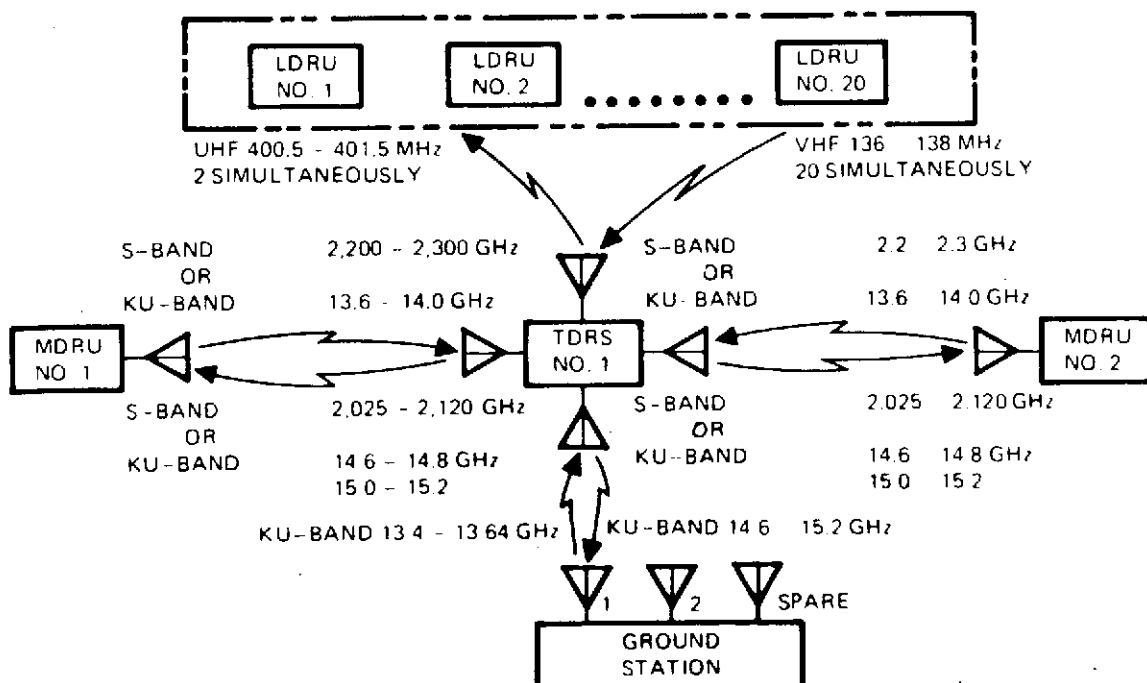


Figure 14-1. Components of the TDRS Telecommunication System
(Typical = One TDRS Satellite)

Table 14-1. Telecommunications Service Requirements
(as per SOW)

Description	LDR User	MDR User	Manned User (Shuttle)
Number of users	Forward: Minimum of 1 Return: 20	Minimum of 1	Minimum of 1
Frequency	Forward: VHF, UHF, S-band Return: VHF	S- or X- or Ku-band	S-band, VHF-band
Communications requirement	Forward: 100 to 1000 bps Return: 1 to 10 kbps	Forward: 100 to 1000 bps Return: 10 to 1000 kbps	Forward: 2 kbps 1 or 2 voice at 19.2 kbps Return: 76.8 kbps 1 or 2 voice at 19.2 kbps
Constraints	<ul style="list-style-type: none"> *Linear transponder in return link *High RFI *Flux density (IRAC): VHF ≤ -144 dBw/m²/4 khz UHF ≤ -150 dBw/m²/4 khz S-band ≤ -154 dBw/m²/4 khz *EIRP = +30 dBw/channel (VHF, UHF) = +41 dBw/channel(S) *BER = 10⁻⁵ 	<ul style="list-style-type: none"> *Linear TDRS transponder return link *Variable frequency *Flux density (IRAC): S-band ≤ -154 dBw/m²/4 khz X-band ≤ -150 dBw/m²/4 khz Ku-band ≤ -152 dBw/m²/4 khz *BER = 10⁻⁵ 	<ul style="list-style-type: none"> *User antenna gain = +3 dB *BER Voice: 10⁻³ Data: 10⁻⁴ *User transmit power = 16 dBw

14-2

SD 72-SA-0133



Table 14-2. System Frequency Plan

	Links	Frequency	Channel Bandwidth
Forward Link	<ul style="list-style-type: none"> LDR MDR <ul style="list-style-type: none"> S-band Ku-band TDRS/GS <ul style="list-style-type: none"> Ku-band VHF S-band Tracking/Order Wire Ku Beacon 	400.5 to 401.5 MHz 2025 to 2120 MHz 14.6 to 15.2 GHz 13.4 to 13.64 GHz 148.26 MHz 2200 to 2290 MHz 2066 MHz 15.0 GHz	1 MHz 4 - 250 KHz channels 95 MHz channel 4 - 100 MHz channels 240 MHz 90 MHz
Return Link	<ul style="list-style-type: none"> LDR MDR <ul style="list-style-type: none"> S-band Ku-band TDRS/GS <ul style="list-style-type: none"> Ku-band VHF S-band Tracking/Order Wire 	136 to 138 MHz 2200 to 2300 MHz 13.6 to 14.0 GHz 14.6 to 15.2 GHz 136.11 MHz 2025 to 2110 MHz 2249 MHz	2 MHz (20 users multiple accessed/TDRS) 20-10 MHz slots in 5 MHz steps or 100 MHz wide open 4-100 MHz channels 200 or 600 MHz channel 85 MHz



14.2 SYSTEM SERVICE AND PERFORMANCE

14.2.1 LDR Return Link

The Adaptive Ground Implemented Phased Array (AGIPA) is the primary mode with F-FOV approach as a back-up for LDR return link functions. This approach provides multiple access support to twenty simultaneous LDR users per TDR satellite. The service characteristics are:

Function	AGIPA Mode	F-FOV Mode
• Telemetry Data No RFI -160 dBm/Hz	13.7 - 20 kbps 5.61 - 16 kbps	4.8 kbps 0.9 kbps
• Voice No RFI -160 dBm/Hz	Yes Yes	Yes No
• Range Error No RFI meter -160 dBm/Hz meter	0.91 - 0.76 1.45 - 0.909	1.2
• Range Error No RFI cm/sec -160 dBm/Hz cm/sec	0.99 - 0.623 0.56 - 0.47	0.8 1.2

Figure 14-2 presents the LDR return link performance as a function of RFI level. The assumptions used in calculating the curves are:

Item	AGIPA Mode	F-FOV Mode
Modulation	Δ PSK	Δ PSK
User EIRP, dBw	4.0	4.0
Losses-Space & Scan	-169.3	-173.1
-Polarization	-0.5	-0.5
TDRS Antenna Gain, dB	16.8	16.8
Syst Noise Temp, dB	30.2	30.2
Δ CNR Degradation, dB	-1.0	-1.0
FEC Coding Gain, dB	4.7	4.7
E_b/N_0 for data, dB	9.9	9.9
C/N_0 for voice, dB-Hz	48.8	48.8
Δ SIR(1) dB	5 -18	

Note: 1. Improvement in signal-to-interference ratio as compared to F-FOV was determined in a RFI model analysis in study.

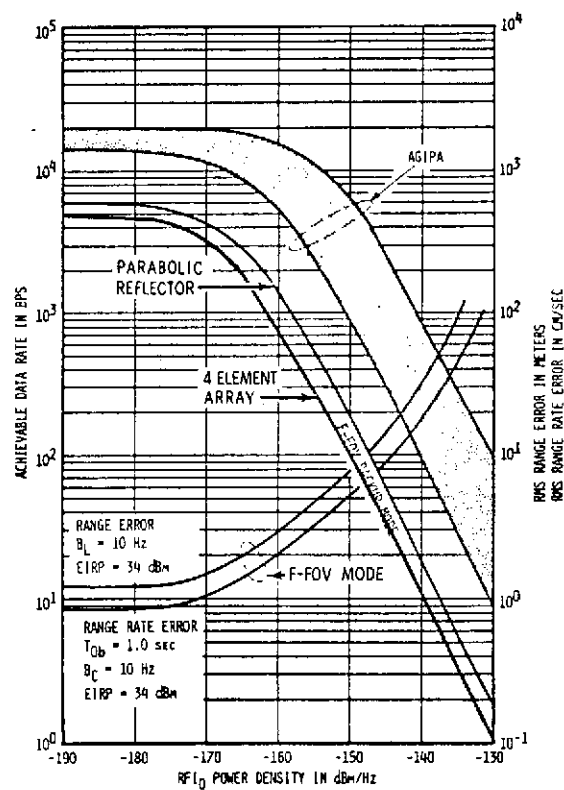


Figure 14-2. LDR Return Link Performance Achievable Bit Rate, Range Error, and Range Rate Error

14.2.2 LDR Forward Link

An electronically steered array provides a high gain beam for each of two channels. Alternatively one element can be used to provide a beam covering the entire thirty-one degrees (0.54 rad) field of view (F-FOV mode). The configuration supports: (1) two simultaneous users in steered array mode, or (2) one user in steered array mode and one user in F-FOV mode. The service characteristics are:

Function	Steered Array Mode (+30 dBw)	F-FOV Mode (+24 dBw)
Command Data		
No RFI	2100 bps	650 bps
-160 dBm/Hz	179 bps	42 bps
Voice		
No RFI	Yes	Yes
-160 dBm/Hz	Yes	Yes
Range Error		
No RFI meter	4.2	7.5
-160 dBm/Hz meter	13.2	26.1
Range Rate Error		
No RFI cm/sec	0.4	0.72
-160 dBm/Hz cm/sec	0.6	1.13

Figure 14-3 presents the LDR forward link performance as a function of RFI. The assumptions used in calculating the curves are:

	Steered Array Mode	F-FOV Mode
Modulation	Δ PSK	Δ PSK
EIRP at 31°(.54 rad) FOV, dBw		
Data	30	24
Voice	36	24
Losses-Space & Scan, dB	-178.1	-178.1
-Polarization, dB	-3.0	-3.0
User Antenna Gain, dBi		
Unmanned	-3.0	-3.0
Manned	0	0
System Noise Temp., dB	26.8	26.8
Δ CNR Degradation, dB	-0.25	-0.25
Design Margin, dB		
Data	3.0	3.0
Voice	11.2	1.1
E_b/N_0 for data, dB	9.9	9.9
C/N_0 for voice, dB/Hz	48.8	48.8

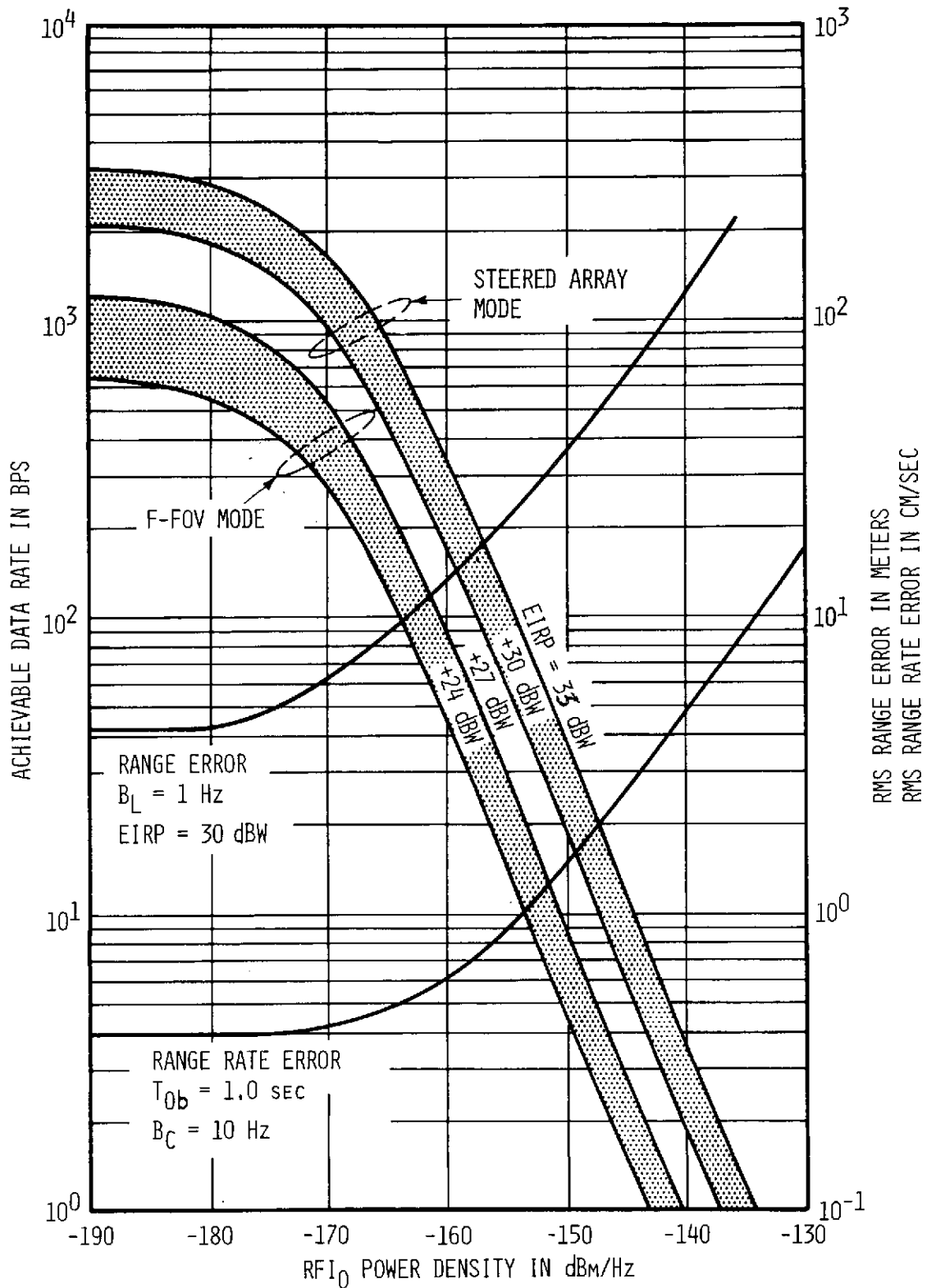


Figure 14-3. LDR Forward Link Performance Achievable Data Rate, Range Error, and Range Rate Error

14.2.3 MDR Link Performance

The MDR transponder on the TDRS provides dual frequency operation in both the forward and return links. S-band is provided to support current users with minimum impact. Ku-band is provided to support future high performance users. The RF interface with the MDR users is provided by two 6.5 feet (2 m) dishes to simultaneously support two S-band users, two Ku-band users, or S-band and one Ku-band user.

Space Shuttle support is provided by the MDR transponders with the following capabilities:

Forward link	One data link at 2 kbps
	One data link at 2 kbps plus one voice link at 19.2 kbps
	One data link at 2 kbps plus two voice links each at 19.2 kbps
Return link	One data link at 76.8 kbps
	One data link at 76.8 kbps plus one voice link at 19.2 kbps
	One data link at 76.8 kbps plus two voice links each at 19.2 kbps

The capability for scientific user support (Spec MDR) is:

Forward link data rate	1000 bps (S or Ku-band)
Return link data rate	10 kbps with 7 dBw EIRP at S- or Ku-band
	1 MBps with 27 dBw EIRP at S- or Ku-band

Figures 14-4 and 14-5 present the MDR return and forward link performance as a function of user S/C ERP and antenna gain respectively. The assumptions used in calculating the curves are:

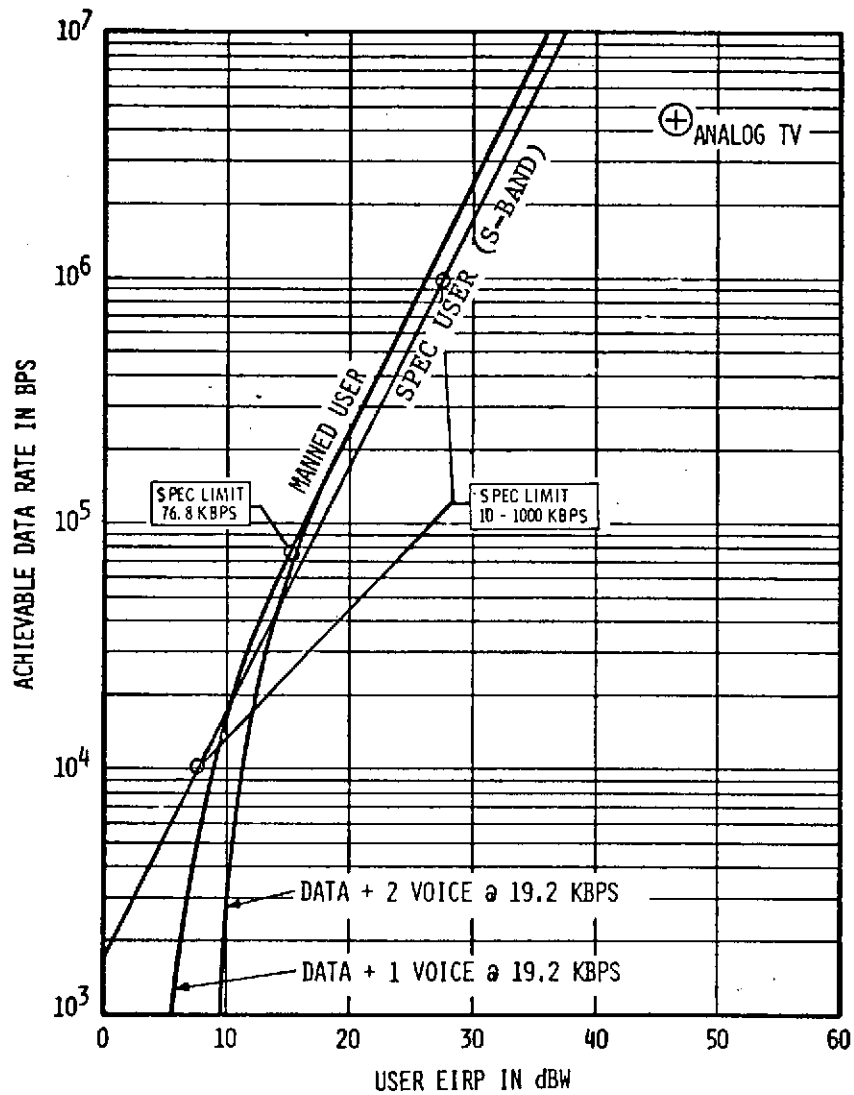


Figure 14-4. MDR Return Link Performance

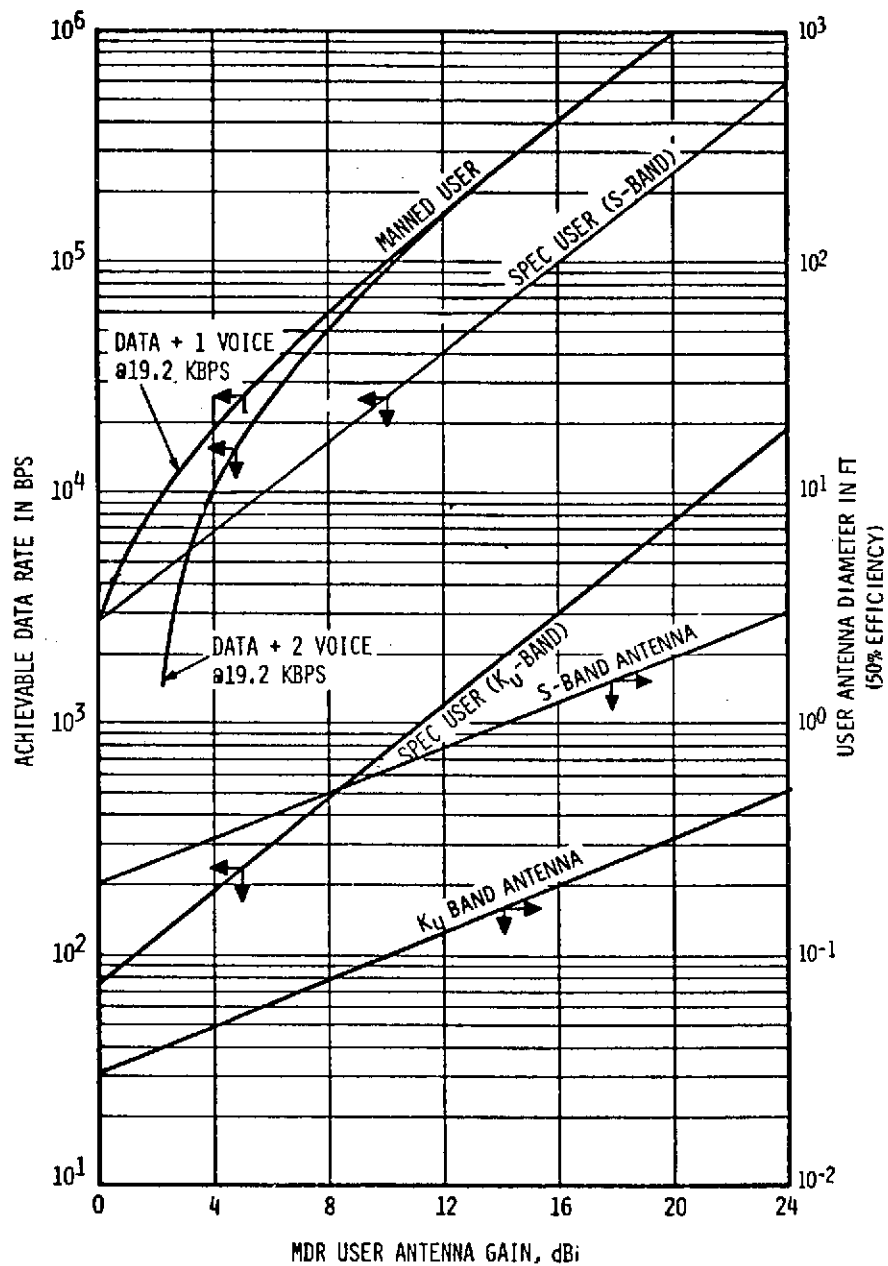


Figure 14-5. MDR Forward Link Performance



Item		Spec S-Band MDR User	Manned MDR User	Spec Ku-Band MDR User
FORWARD LINK	TDRS EIRP, dBw	41.0	41.0/47.0(4)	45.8
	Space loss, dB	192.0	192.0	208.1
	Other losses (1) dB	1.1	1.1	1.1
	User antenna gain, dBi	G_u	3.0	G_u
	User system noise temp., dB	29.1	27.3 (2)	33.5 (3)
	Design margin, dB	3.0	3.0	3.0
	C/N_0 available dB/Hz	$44.4 + G_u$	49.2/55.2	$28.7 + G_u$
RETURN LINK	TDRS system noise temp. (5), dB	26.2	26.2	26.2
	Space loss (5) dB	191.1	191.1	191.1
	Other losses (1) dB	1.6	1.1	1.1
	FEC coding gain (6)	4.7	4.7	4.7
	Design margin, dB	3.0	3.0	3.0
	TDRS antenna gain, dBi	30.9	30.9	30.9

- (1) Combined polarization, pointing and Δ CNR degradation
- (2) Uncoded paramp
- (3) Tunnel diode amplifier
- (4) 6 dB increased EIRP for voice mode
- (5) Values selected at a point where the product of loss and system temperature maximizes.
- (6) Forward error control ($R = 1/2$, $K = 7$ convolutional code; Viterbi decoder).

14.3 LINK BUDGET

14.3.1 LDR Return Link Budget

The LDR return link operates in the 136-138 MHz VHF band, and uses an adaptive process called AGIPA in its primary mode, and F-FOV as a backup mode. The link performance was calculated as shown in Table 14-3 using the following expression to compute the achievable data rate (H):

$$H = \frac{P_u \text{ (FEC)}}{\text{CNR} \left[N_i + \frac{1}{\Delta \text{SIR}} \left(\text{RFI}_o + M_o + D_o \right) \right]} \quad (1)$$

Where:

CNR = required CNR

N_i = input thermal noise density at TDRS

P_u = $(\text{EIRP})_{\text{User}} \times G_{\text{TDRS}} \times L_t$ = received user power at TDRS

L_t = all losses including space, polarization, and scan

FEC = forward error control

ΔSIR = improvement in signal-to-interference ratio provided by AGIPA

RFI_o = unintentional interference signal power density

M_o = intentional multipath interference signal from desired and other in-band LDR users

$$= \frac{1}{\text{CR}} \left\{ K \left[\frac{4 P_u}{\infty} + \frac{n-1}{20} \times R \times P_u \right] \right\}$$

CR = PN chip rate

K = an attenuation factor proportional to the reflection coefficient = 1.0

n = the number of users/channel = 20

R = the ratio of average multipath contribution of other users to the desired signal power (≈ 7 dB for the 1976 user s/c distribution)

= $2h/300$; h = user altitude = 300 km (worst case for multipath)

D_o = intentional direct interference signal from other in-band LDR users

= $(n-1) P_u / \text{CR}$

The sample link calculation was computed for an RFI_o of -160 dBm/Hz, and user EIRP of +4 dBw. The ΔSIR improvement is a minimum value based on results of an RFI model analysis conducted during the study.

The calculation shows that even in the relatively large RFI environment of -160 dBm/Hz that AGIPA (with minimum adaptive processing gain) provides over 5 kbps of data, and/or voice with considerable margin. The F-FOV mode can support approximately 1 kbps of data but requires higher EIRP to support voice.

Table 14-3. LDR - Return Link Budget

		AGIPA Mode		F-FOV Mode	
		Data	Voice ⁽¹⁾	Data	Voice ⁽¹⁾
Modulation		Δ PSK	Δ PSK	Δ PSK	Δ PSK
User EIRP	dBw	4.0	7.0 ⁽²⁾	4.0	7.0 ⁽²⁾
TDRS antenna gain (peak)	dBi	16.8	16.8	16.8	16.8
Losses - space + scan ⁽⁷⁾	dB	-169.3	-169.3	-173.1	-173.1
- polarization	dB	- 0.5	- 0.5	- 0.5	- 0.5
Received power	dBw	-149.0	-146.0	-152.8	-149.8
System noise temperature	dB	30.2	30.2	30.2	30.2
Noise density - thermal	dBw/Hz	-198.4	-198.4	-198.4	-198.4
multipath	dBw/Hz	-200.7	-200.7	-200.7	-200.7
Other direct signal	dBw/Hz	-196.7	-196.7	-196.7	-196.7
RFI _O	dBw/Hz	-190.0	-190.0	-190.0	-190.0
Total noise density	dBw/Hz	-188.4	-188.4	-188.4	-188.4
TDRS Δ CNR degradation ⁽³⁾	dB	-1.0	-1.0	-1.0	-1.0
C/N _O	dB-Hz	38.4	41.4	34.6	37.6
FEC coding gain ⁽⁵⁾	dB	4.7	4.7	4.7	4.7
Available C/N _O (w/o AGIPA process gain)	dB-Hz	43.1	46.1	39.3	42.3
E _b /N _O ⁽⁶⁾		9.9	--	9.9	--
AGIPA process gain ⁽⁴⁾	dB	4.3 ⁽⁹⁾	4.3 ⁽⁹⁾	--	--
Achievable bit rate	dB	37.5	--	--	--
	bps	5610	--	871	--
Required C/N _O for voice	dB-Hz	--	48.8	--	48.8
Design margin	dB	--	1.6	--	-6.5 ⁽¹⁰⁾

NOTES

1. Voice is delta modulated, 19.2 kbps at $P_e = 10^{-3}$ and requires a C/N_O of 48.8 dB-Hz.
2. Manned user assumed to have directional antenna with 0 dBi gain.
3. A CNR degradation (Δ CNR) of 1.0 dB assumed for the TDRS transponder.
4. Worst case AGIPA processing gain included. Actual AGIPA performance in RFI model has shown 5 to 18 dB signal-to-interference ratio improvement over F-FOV approach.
5. Coding gain achieved with Forward Error Control (FEC) using Rate 1/2 constraint length 7 with a Viterbi decoder.
6. E_b/N_O = 9.9 for Δ PSK at $P_e = 10^{-5}$.
7. Worst case combination of space and scan losses since they do not maximize at the same spacecraft aspect angle.
8. Chip rate (CR) = 10^6 bps.
9. AGIPA processing gain of 6.5 dB as compared to F-FOV approach, or 4.3 dB is compared to nonadaptive AGIPA.
10. For equivalent performance as AGIPA, the EIRP must be increased (7.0 + 6.5 + 1.6) to 15.1 dBw or 32.4 watts.



14.3.2 LDR Forward Link Budget

The LDR Forward Link operates in the 400.5 - 401.5 MHz UHF band, and provides two forward channels for voice and/or data. Both channels can operate in a high gain steerable beam mode, or one channel can be operated in a low gain F-FOV mode. Sample link calculations have been made, as shown in Table 14-4, for both data and voice transmissions in both steerable beam and F-FOV modes, using the following expression for command data rate (H):

$$H = \frac{P_u}{\text{CNR} \left\{ N_1 + \text{RFI}_O + \frac{1}{\text{CR}} \left[\frac{4 P_u}{\infty} \right] \right\}} \quad (2)$$

where the parameters are as defined for equation (1).

In the calculation, the worst case combination of the space loss and scan loss have been used, since the individual worst cases do not occur simultaneously.

The link calculation shows that in the presence of -160 dBm/Hz RFI environment that peak command data of 272 bps and 76.8 bps can be supported in the steerable beam and F-FOV modes, respectively. Voice can be supported in the AGIPA mode with over 10 dB margin, but will require forward error control coding gain of 4.4 dB in the F-FOV mode to provide a margin of 3 dB.

14.3.3 MDR Return Link Budgets

The MDR return link power budgets for S-band (spec user and manned user) and Ku-band are presented in Tables 14-5 and 14-6, respectively. The objective here is to develop an estimate for the required user EIRP for various levels of mission support. To compute the EIRP required, the following equation was used:

$$\text{EIRP}_{\text{required}} = \left(\frac{C}{N_o} \right)_{\text{required}} + \text{Boltzmanns Const.} \left(-228.6 \frac{\text{dBw}}{\text{°K-Hz}} \right) + \text{TDRS System Noise Temperature} + \text{Path Loss} + \text{Other Losses} - \text{TDRS Antenna Gain} + \text{Forward Error Control} + \text{Design Margin.}$$

The required $\left(\frac{C}{N_o} \right)$ is based on the type of service and performance desired over the link. The values for TDRS system temperature and path loss were chosen for the point where their combined effect is maximum. Other losses referred to are the combination of pointing, polarization and TDRS Δ CNR degradation. A forward error control coding gain of 4.7 dB was added to the link budget so that the system will have maximum return link performance with minimum impact on the user EIRP requirements.

With the exception of the manned user the transmit power P_T required is expressed in terms of dBw- G_u , where G_u is the user antenna gain. The required P_T then will decrease as the user antenna gain increases. For example, the 1 Mbps link requires a P_T of 27.6 dBw- G_u ; if the user antenna gain is on the order of 20.7 dBi then P_T is on the order of 7 dBw or 5 watts. For the manned user G_u is fixed at 3 dBi, thereby fixing the shuttle required P_T somewhere between 11.79 and 46.44 dBw depending on the service required.

Table 14-4. LDR - Forward Link Budget at UHF

	Steerable Beam Mode		F-FOV Mode	
	Data	Voice (1)	Data	Voice
Modulation	Δ PSK	Δ PSK	Δ PSK	Δ PSK
Transmitter Power, dBW	13.0	19.0	13.0	13.0
TDRS Antenna Gain (peak) dBi	21.0	21.0	15.0	15.0
Transmit Line Losses (2), dB	1.0	1.0	1.0	1.0
EIRP (peak), dBW	33.0	39.0	27.0	27.0
Losses - Space & Scan (3), dB	-178.1	-178.1	-178.1	-178.1
- Polarization, dB	-3.0	-3.0	-3.0	-3.0
User Antenna Gain, dBi	-3.0	+0.0(4)	-3.0	0.0(4)
Received Power, dBW	-151.1	-142.1	-157.1	-154.1
System Noise Temp., dB	26.8	26.8	26.8	26.8
Noise Density - Thermal, dBW/Hz	-201.8	-201.8	-201.8	-201.8
- Multipath	-197.8	-(4)	-197.8	-(4)
- RFI, dBW/Hz	-190.0	-(4)	-190.0	-(4)
Total Noise Density, dBW/Hz	-189.1	-201.8	-189.1	-201.8
TDRS Δ CNR Degradation (5), dB	-0.25	-0.25	-0.25	-0.25
Available C/N ₀ , dB	37.25	59.45	31.75	47.45
E _b /N ₀ (6), dB	9.9		9.9	
Design Margin, dB	3.0	10.65	3.0	-1.35(8)
Achievable Bit Rate, dB	24.35		18.85	
bps	272.0		76.8	
Required C/N ₀ for voice		48.8		48.8
Notes: (1) Voice is delta modulated, 19.2 kbps at $P_e = 10^{-3}$ and requires a C/N ₀ of 48.8 db-Hz. (2) No diplexer required in dual VHF-UHF antenna design. (3) Worst case combination of the space loss and scan loss since they do not maximize at the same spacecraft aspect angle. (4) For the manned user, a directional antenna providing 0 dBi gain toward the TDRS satellite has been assumed, and rejecting all interference signals. (5) A CNR degradation (Δ CNR) of 0.25 dB assumed for the TDRS transponder. (6) E _b /N ₀ = 9.9 for PSK at $P_e = 10^{-5}$. (7) CR = (Chip Rate) = 167 kcps. (8) Total margin must include +1.35 dB plus the desired design margin.				

14-15

SD 72-SA-0133

Table 14-5. MDR Return Link Budget (S-Band)

Item	MDR User			Manned User (Space Shuttle)			
	10 kbps ¹	1000 kbps ¹	Analog TV ²	Data ³ (76.8 kbps)	Data + 1 Voice ⁴	Data + 2 Voice	Analog TV
C/N ₀ required, dB-Hz	49.9	69.9	87.54	57.59	58.17 ⁵	58.50 ⁶	87.54
FEC coding gain, dB	4.70	4.70		4.70	4.70	4.70	
Effective C/N ₀ , dB-Hz	45.2	65.2	87.54	52.89	53.47	53.80	87.54
Path loss ⁷ , dB	191.1	191.1	191.1	191.1	191.1	191.1	191.1
System temperature ⁷ , dB	26.2	26.2	26.2	26.2	26.2	26.2	26.2
Boltzmann's const, dBW/°K-Hz	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6
Pointing loss, dB	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Polarization loss, dB	0.5	0.5	0.5	0.5	0.5	0.5	0.5
G _{user} , dBi	G _u	G _u	G _u	3.0	3.0	3.0	3.0
GTDRS, dBi	30.9	30.9	30.9	30.9	30.9	30.9	30.9
ΔCNR degradation, dB	1.0	1.0	1.0	0.5	0.5	0.5	0.5
System margin, dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Required EIRP, dBw	7.6	27.6	49.94	14.79	15.37	15.70	49.44
Transmit power ⁸ , dBw	7.6 - G _u	27.6 - G _u	49.94 - G _u	11.79	12.37	12.7	46.44

NOTES

- 1 ΔPSK; BER = 10⁻⁵ (E_b/N₀ = 9.9 dB)
- 2 Commercial quality (S/N)₀ = 40 dB; BW = 4.5 MHz
- 3 ΔPSK; BER = 10⁻⁴ (E_b/N₀ = 8.7 dB)
- 4 Voice is delta modulated at 19.2 kbps; carrier modulation is ΔPSK (BER = 10⁻³; C/N₀ = 48.8 dB-Hz)
- 5 Combine value of data (C/N₀ = 57.59) and one voice (C/N₀ = 48.8)
- 6 Combine value of data (C/N₀ = 57.59) and two voice (C/N₀ = 51.8)
- 7 This value is selected at the point where the product of the path loss and system temperature is maximum
- 8 Transmit power into antenna

Table 14-6. MDR Return Link Budget (Ku-Band)

Item	10 kbps ¹	1000 kbps ¹	Analog TV ²
C/N ₀ required, dB - Hz	49.9	69.9	87.54
FEC coding gain, dB	4.7	4.7	-
Effective C/N ₀ , dB - Hz	45.2	65.2	87.54
Path loss ³ , dB	208.1	208.1	208.1
System temperature ³ , dB	26.7	26.7	26.7
Boltzmann's const., dBW/°K - Hz	-228.6	-228.6	-228.6
Pointing loss, dB	0.1	0.1	0.1
G _{user} , dB	G _u	G _u	G _u
GTDRS, dB	47.1	47.1	47.1
ΔCNR degradation, dB	0.5	0.5	0.5
System margin	3.0	3.0	3.0
Required EIRP, dBw	7.9	27.9	50.2

- 1 ΔPSK; BER = 10⁻⁵ (E_b/N₀ = 9.9 dB)
- 2 Commercial quality (S/N)₀ = 40 dB; BW = 4.5 MHz
- 3 This value is selected at the point where the product of path loss and system temperature is maximum.

The sensitivity of the system noise temperature (T_s) to the noise temperature (T_{e1}) of the parametric amplifier for the MDR S-Band Receiver was also computed and is shown in Figure 14-6. The expressions used for the curve are:

$$\begin{aligned} T_s &= T_a + T_r \\ T_r &= T_o (L_1 - 1) + T_{e1} (L_1) + T_{e2} (L_1) / G_1 + \dots \dots \dots (3) \\ &= 116 + 1.4 T_{e1} + 12.6 = 128.6 + 1.4 T_{e1} \end{aligned}$$

Where the parameters used in the equation are defined in the block diagram in the same figure. The antenna temperature (T_a) of 234° K is the worst case temperature as seen by the MDR receiver. For the predicted device temperature of 50° K for the 1974 time period, the resultant system noise temperature is 26.15dB or 410° K. On the other hand if a conservative design employing existing (1972) technology of 100° K is used, the system noise temperature increases by only 0.5 dB.

14.3.4 MDR Forward Link Budgets

The forward link power budgets for the Medium Data Rate user is presented in Table 14-7 for three generic user types; namely, the spec (or scientific) MDR user operating at S-band, the Manned user (Space Shuttle), and the Spec-MDR user operating at K_u -band. In the table, the available carrier-to-noise density ratio (C/N_o) was computed to assess the overall performance of each. The expression used to compute (C/N_o) is as follows:

$$\left(\frac{C}{N_o} \right)_{\text{Available}} = \text{EIRP} - \text{Free Space Loss} + \text{User Antenna Gain} - \text{Other Losses}^* + \text{Boltzmanns Constant} - \frac{(-228.6 \text{ dBw})}{0 \text{ K-Hz}} + \text{User System Noise Temperature}$$

* Other losses comprise pointing, polarization, and TDRS Δ CNR degradation losses.

For the MDR S- and K_u -band Spec user, C/N_o is in terms of dB-Hz + G_u (the user antenna gain), implying that any addition of user gain produces a corresponding increase in C/N_o . For the Spec MDR S-band user, the required maximum forward link support of 1 Kbps can be achieved with a system margin of 8.7 dB + G_u (dB). Likewise, the Spec MDR K_u -band user can be provided with forward link support of 75 X G_u bps (i.e., if the MDR user spacecraft carries a K_u -band antenna having a gain of 20 db (100) the forward link data rate which can be supported is 7.5 kbps.)

The manned user link has a C/N_o of 53.4 db-Hz available. As can be seen from the table, forward error control coding is required to support 1 data link (2 kbps) and 2 voice links (each at 19.2 kbps).

14.3.5 TDRS-to-Ground Station Return Link Budget

The TDRS-to-Ground Station return link operates in the 14.6 to 15.2 GHz K_u -band, and must operate in the presence of rain in the earth's atmosphere. This link has a margin of 7.5 dB during normal, clear weather operation, and an additional 10 dB power amplification is provided for operation in rain.

Table 14-7. MDR Forward Link Budget

Item		MDR S-Band User		Manned User (Space Shuttle)		MDR Ku-Band User	
Modulation		Δ PSK		Δ PSK		Δ PSK	
Transmitter power	dBw	12.5		12.5/18.5		-2.0	
TDRS antenna gain	dB	29.8		29.8		48.1	
Transmit line losses	dB	1.3		1.3		1.0	
EIRP	dBw	41.0		41.0/47.0 ⁷		45.1	
Losses							
Space	dB	-192.0		-192.0		-208.1	
Pointing	dB	-0.1		-0.1		-0.1	
Polarization	dB	-0.5		-0.5		-0.5	
User antenna gain	dB	G_u		3.0		G_u	
Received power	dBw	$-151.6 + G_u$		$-148.6/-142.6$		$-163.6 + G_u$	
System noise temperature	dB	29.1		27.3 ¹		33.5 ⁵	
Thermal noise density	dBw/Hz	-199.5		-201.3		-195.1	
TDRS Δ CNR degradation	dB	-0.25		-0.25		-0.25	
Available C/N ₀	dB-Hz	$47.65 + G_u$		52.45/58.45		$31.25 + G_u$ ⁶	
Support Requirements		100 bps ²	1000 bps	Data ³	Data + 1 Voice ⁴	Data + 2 Voice ⁴	BER = 10^{-5} (Δ PSK)
C/N ₀ required	dB-Hz	29.9	39.9	41.7	49.6	52.4	--
Data rate achievable	bps	--	--	--	--	--	$68.4 \times G_u$ ⁶
Design margin	dB	$17.75 + G_u$	$7.75 + G_u$	10.75	8.85	6.05	3.0
NOTES 1 Noise temperature with an uncooled paramp. 2 For Δ PSK with a BER = 10^{-5} ($E_b/N_0 = 9.9$ dB) 3 Data = 2 kbps Δ PSK with BER = 10^{-4} ($E_b/N_0 = 8.7$ dB) 4 Voice is delta modulated at 19.2 kbps; carrier modulation is Δ PSK (BER = 10^{-3} ; ($C/N_0 = 48.8$ dB-Hz) 5 Tunnel diode amplifier 6 A 1.0 ft (.3 m) antenna at Ku-band provides about 28.5 dB gain (i.e., a factor of about 800) providing an achievable bit rate of about 55 kbps 7 Increased EIRP used for voice mode only							

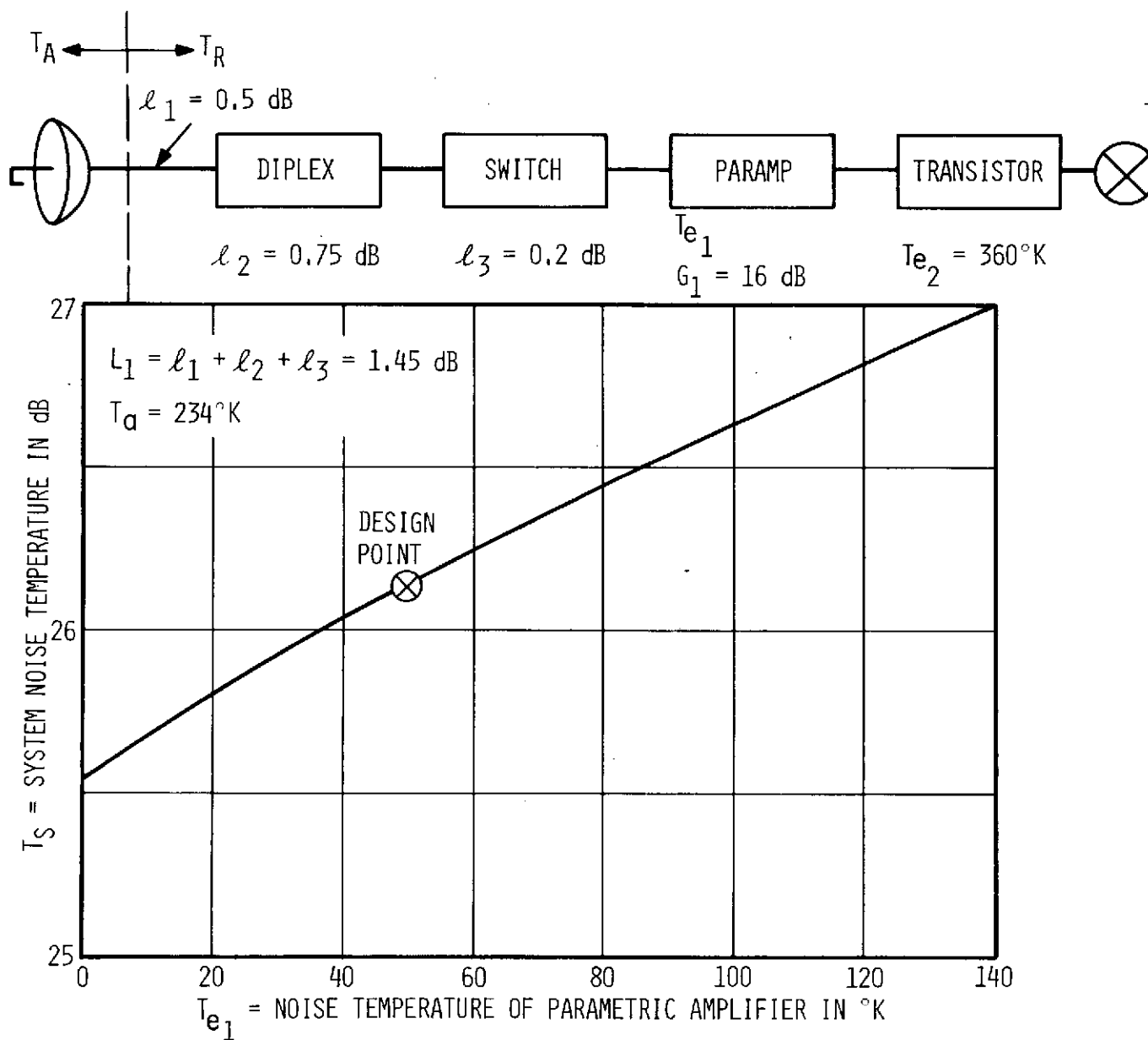


Figure 14-6. System Noise Temperature Vs Noise Temperature of Parametric Amplifier

This link is sized for the worst case of transmitting TV to the GS, using FDM/FM. The index of modulation is 0.94 using a phased locked demodulator at the GS.

The link power budget is computed using the following equation:

$$P_{TDRS} = \frac{(CNR_0) (KT_S B) \propto_T}{G_{TDRS} G_{GS}}$$

where:

T_S = system noise temperature, including the antenna and receive thermal temperatures

$KT_S B$ = system noise power

G_{TDRS} = three foot (0.91m) aperture at TDRS

G_{GS} = sixty foot (18.3m) aperture at GS

\propto_T = total losses including space, pointing, polarization, transmit line (component losses)

B = RF bandwidth

CNR_0 = CNR required for FM

The resultant link budget is shown in Table 14-8, and shows that a TDRS transmitter power of 2.75 watts is required for operation in rain, and 0.275 watt for clear weather operation.

14.3.6 Ground Station-to-TDRS Forward Link Budget

The CNR required for the GS-to-TDRS-to-User link was computed using the tandem link equation to determine the required CNR for the GS-to-TDRS portion of the tandem link using the following equation:

$$CNR_F = \left(CNR_{TDRS} \times CNR_{GS} \right) / \left(CNR_{TDRS} + CNR_{GS} + 1 \right)$$

where:

CNR_F = final CNR required

CNR_{TDRS} = CNR required in the space-to-space link

CNR_{GS} = CNR required in the ground-to-space link

The results of the CNR's computation are shown in Figure 14-7 for the LDR and typical MDR modes, and are used in Table 14-9 to compute the TDRS transmit power requirement for this link. Since the MDR-TV requires the largest transmit power, it has been used to size the transmitter using the following link equation:

$$P_{TDRS} = \frac{(CNR_F) (KT_S B) \propto_T}{G_{TDRS} G_{GS}}$$

Table 14-8. TDRS-to-Ground Station Return Link Budget

Modulation	FDM/FM
CNR Required	0dB (1)
RF Bandwidth	600. MHz (2)
GS System Noise Temperature	25.2 dB (3)
Thermal Noise Power	-115.6 dBw
GS Antenna Gain	67.9 dBi (4)
Losses - Space	-208.1 dB
- Pointing	-1.0 dB
- Polarization	-0.5 dB
- Transmit Line/Others	-1.0 dB
Rain Margin	17.5 dB (5)
EIRP Required at TDRS	44.6 dBw
TDRS Antenna Gain	40.3 dBi
<hr/>	
TDRS Transmit Power Req'd.	4.3 dBw
	2.75 watt - for rain
	0.275 watt - for clear weather

- Notes: (1) FM modulation with modulation index of 0.94 with phase locked demodulator.
(2) For TV transmission.
(3) Two uncooled paramps in cascade each with T_e of 130°K.

$$T_s = T_a + (L_1 - 1) T_o + L_1 T_{e1} + (L_1 T_{e2} / G_1) + \dots$$

$$= 18 + (0.43) 290 + 1.43 \times 130 + (1.43 \times 130 / 100) = 329^\circ K = 25.2 \text{ dB}$$

(4) 18.3 m aperture with 75% efficiency
(5) Rain margin provides operation in 25 mm/hr rainfall rate.

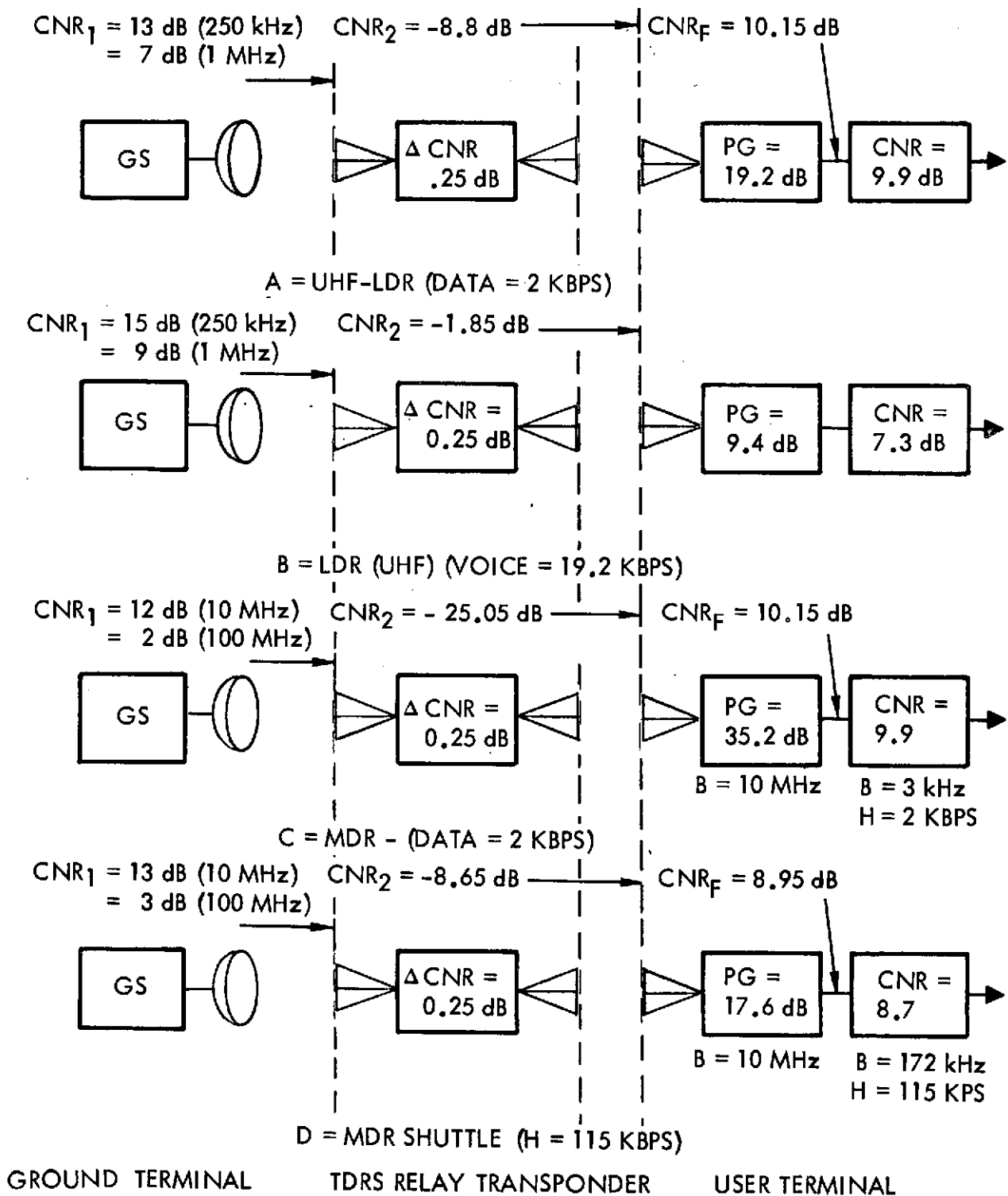


Figure 14-7. CNR Calculation in TDRS/GS Forward Link

Table 14-9. Ground Station-to-TDRS Forward Link Budget

Parameter	LDR Data	LDR Voice	MDR Data	MDR - Shuttle Data + 2 Voice
Modulation	Δ PSK	Δ PSK	Δ PSK	Δ PSK
Data Rate, kbps	1.0	19.2	2.0	115.0
CNR Required (1), dB	7.0	9.0	2.0	3.0
RF Bandwidth, MHz	1.0	1.0	100.0	100.0
System Noise Temperature (2), dB	33.6	33.6	33.6	33.6
Thermal Noise Power, dBw	-135.0	-135.0	-115.0	-115.0
TDRS Antenna Gain, dBi	39.6	39.6	39.6	39.6
Losses: Space, dB	-207.2	-207.2	-207.2	-207.2
Pointing, dB	-1.0	-1.0	-1.0	-1.0
Polarization, dB	-0.5	-0.5	-0.5	-0.5
Atmospheric, dB	-0.4	-0.4	-0.4	-0.4
Transmit Line/Others, dB	-5.9	-5.9	-5.9	-5.9
Rain Margin (3), db	17.5	17.5	17.5	17.5
EIRP Required, dBw	64.9	66.9	79.9	80.9
GS Antenna Gain (4), dBi	67.0	67.0	67.0	67.0
GS Transmit Power Required, dBw	-2.0	-0.1	12.9	13.9
GS Transmit Power Required, watts	0.63	1.0	19.5	24.5

- NOTES: (1) See Figure A-7 for the required CNR for the GS/TDRS link.
 (2) Uses mixer front end.
 (3) Rain margin provides operation in 25mm/hr rainfall rate.
 (4) Sixty feet (18.3m) aperture with seventy-five percent efficiency

where:

- T_S = system noise temperature, including antenna and receive thermal temperature
- $KT_S B$ = system noise power
- G_{TDRS} = three foot (0.91m) aperture at TDRS
- G_{GS} = sixty foot (18.3m) aperture at GS
- α_T = total losses including space, pointing, polarization, transmit line (component losses)
- B = RF bandwidth

14.3.7 Tracking/Order Wire Link Budget

The Tracking/Order Wire Transponder operates in the S-band spectrum and provides three associated telecommunication functions, viz:

- Tracking and position location of the TDR satellite using trilateration ranging with two remote GS and the TDRS GS.
- Order wire receiver to establish order of priority access to the S-band MDR channel.
- S-band beacon for S-band MDR users employing steerable antenna

Typical link calculations were made for both forward and return link operations as shown in Table 14-10.

14.3.8 Ku-Band Beacon Link Budget

The Ku-band beacon is used as a source by Ku-band MDR users with steerable antennas to acquire and track the TDRS satellite. This beacon can also be used by the GS as a pilot signal to coherently lock its frequency source, in the event the normal mode where the TDRS locks-on to the GS pilot signal cannot be established. The sample link calculation is shown in Table 14-10 for the TDRS to user case to size the transmitter requirements.

14.4 SUBSYSTEM TERMINAL CHARACTERISTICS

14.4.1 TDRS Telecommunication Subsystem

The TDRS Telecommunication System includes the Telecommunication Service System, and the Tracking, Telemetry and Command (TT&C) System. A functional block diagram of the Telecommunication System is shown in Figure 14-8 and includes:

- LDR Transponder
- MDR #1 Transponder
- MDR #2 Transponder

Table 14-10. TDRS Tracking/Order Wire Transponder and Ku-Band Beacon Link Budgets

	Tracking/Order Wire Transponder		Ku-Band Beacon
	Forward	Return	
Transmitter Power, dBw	3.0	16.0 ⁽¹⁾	1.5
Transmit Antenna Gain, dBi	14.5	3.0 ⁽¹⁾	12.0
Transmit Losses, dB	-3.0	-3.0	-0.5
EIRP, dBw	14.5	16.0 ⁽¹⁾	13.0
Losses: Space, dB	-191.0	-192.4	-208.1
Polarization, dB	-1.0	-1.0	-1.0
Receive Antenna Gain, dBi	43.0	12.0	30.0 ⁽⁵⁾
Received Power, dBw	-135.0	-165.4	-166.1
Thermal Noise Density, dBw/Hz	-206.8	-201.1	-203.8
System Noise Temperature, dB	21.8	27.5 ⁽²⁾	24.8
TDRS ACNR Degradation, dB	-0.5	-0.5	-
Available C/N_o , dB-Hz	⁽³⁾ 71.8	35.2	37.7
E_b/N_o , dB-Hz		9.9	
Design Margin, dB		5.0	5.0
Achievable data rate, dB		20.3	32.7
Achievable data rate, bps		≈100.0	

- Notes:
- (1) Assumed Space Shuttle as user.
 - (2) Transistor with $T_e = 360$ K
 - (3) For $C/N_o = 71.8$ dB-Hz and a chip duration of 2×10^{-6} sec the one way ranging error (ΔR) for the TDRS/GS link is 7×10^{-2} meters.
 - (4) This is more than adequate to provide order wire service.
 - (5) Assumes that a high performance Ku-Band MDR user will have at least 30 dBi antenna gain.

- TDRS/GS Transponder
- Frequency Source
- Tracking/Order Wire Transponder
- Ku-Band Beacon
- TT&C

The major characteristics of the Telecommunication System are shown in Table 14-11, and a size, weight, power summary is shown in Table 14-12.

14.4.2 User Transponder Design

14.4.2.1 LDR Transponder on User S/C

A simplified schematic block diagram of the LDR transponder is shown in Figure 14-9. The receiver is designed to tune to any one of four UHF carrier frequencies used by the two TDRSs. The carrier in the forward link is phase modulated by a 167 Kchip/sec pseudonoise (PN) sequence to discriminate against multipath and to distribute the signal energy radiated from the TDRS to conform to the IRAC requirements. A 1 Mchip/sec PN sequence is used in the return link to permit code division multiple access of 20 LDR users through a common channel in the TDRS with sufficient process gain to achieve a specific level of performance for any one user in the face of nineteen interfering users. The use of PN sequences in both the forward and return links provides a vehicle for deriving range information.

The data is delta PSK modulated with convolutional encoding to save power through error control. The demodulation process in the receiver is rather straightforward. The transmitter, except for the PN modulation, is a standard transmitter configuration.

A preliminary estimate of the size and prime power requirements of the user LDR transmitter and receiver are: transmitter - power, 16 watts; size, 225 in³ (3700cc); and receiver - power, 12 watts; size, 195 in³ (3200cc).

The characteristics of the LDR user terminal are summarized in the following:

LDR User Terminal Characteristics

Forward Link

- | | |
|---------------------------------------|--|
| •Data Rate | 100 bps to 1000 bps |
| •Carrier frequency | 400.5 to 401.5 MHz
(4 - 250 KHz channels) |
| •PN Modulation | 167 Kchips/sec |
| •Code Length | Short - 2047 chips
Long - Eleven 2047 |
| •One PN Code Sequence
To All Users | |

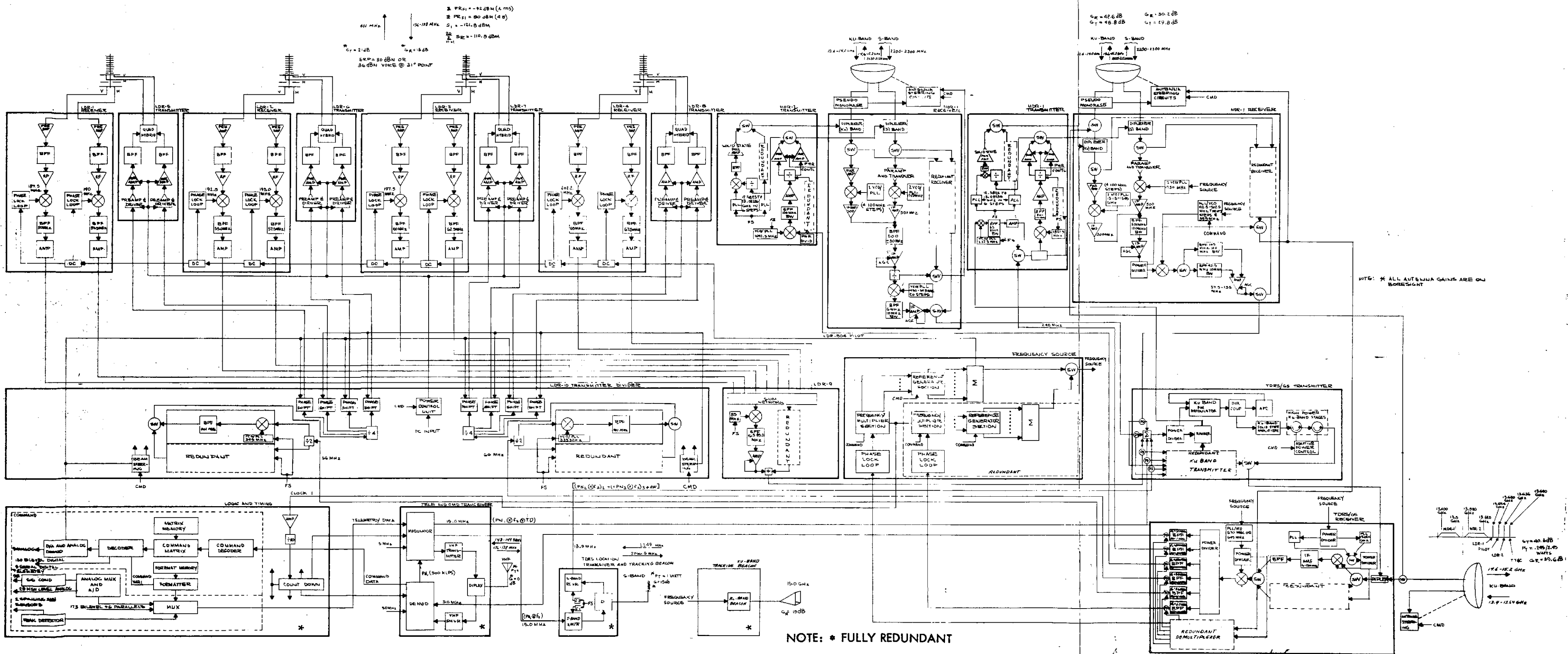


Table 14-11. Telecommunication Transponder Characteristics

Parameter	LDR Transponder	MDR #1 & #2 Transponder	TDRS/GS Transponder
Antenna	<ul style="list-style-type: none"> • Dual Freq. (VHF/UHF) Quad-Array • Gain: 15 dBi (VHF) 21 dBi (UHF) 	<ul style="list-style-type: none"> • Dual Freq. 2 meter dish - Cassegrain for Ku-band - Prime Focus for S-band • Gain: ≈ 30.2 dBi (S) ≈ 48.3 dBi (Ku) 	<ul style="list-style-type: none"> • Ku-band 0.9 meter dish • Gain: ≈ 40 dBi
Receiver <ul style="list-style-type: none"> • Frequency • Type • Bandwidth 	<ul style="list-style-type: none"> • 136 - 148 MHz • Linear • 2 MHz/channel x 8 channels 	<ul style="list-style-type: none"> • 2.2-2.3 or 13.6-14.00 GHz • Linear • 20-10 MHz tuneable in 5 MHz steps or 100 MHz wide band at S-band; and 4-100 MHz at Ku-band • S-band paramp ($T_e = 50$ K) + transistor ($T_e = 360$ K) • Ku-band paramp ($T_e = 100$ K) 	<ul style="list-style-type: none"> • 2.2-2.3 or 13.4-13.6 GHz • Linear • 240 MHz • Mixer (NF = 6 dB)
Transmitter <ul style="list-style-type: none"> • Frequency • Bandwidth • Transmitter RF Power 	<ul style="list-style-type: none"> • 400.5-401.5 MHz • 1 MHz • 5 or 20 watts/channel x 8 channel (4 channels per each forward link) 	<ul style="list-style-type: none"> • 2.025-2.12 or 14.6-14.8 and 15.0-15.2 GHz • 95 MHz at S and 4 selectable 100 MHz at Ku • S-band: 14 or 56 watts Ku-band: 0.56 watts 	<ul style="list-style-type: none"> • 2.025-2.11 or 14.6-15.2 GHz • 200 or 600 MHz • 2.75 or 0.275 watts

Table 14-12. Telecommunications Subsystem Size, Weight, and Power Summary

Subsystem	Size		Weight		Power	
	in.	cm	lb	kg	Peak	Average
LDR						
Receiver (4)	8x7x.5	20.2x17.8x1.27	7.6	3.5		7.93
I.F. Summing Network	4x7x0.5	10.2x17.8x1.27	1.3	0.6		1.14
Transmitter (4)	10x2.62x1.12	25.4x6.7x2.84	4.5	2.0	137.6	34.40
Trans. Divider Network	10x7.5x2.25	25.4x19.0x5.7	5.1	2.31		11.40
Antenna, incl stem unit and support link			31.6	14.35		
MDR NO. 1						
Receiver	12x8x4	30.5x20.4x10.2	8.8	4.0	6.2	6.2
Transmitter	6x4.50x10	15.3x11.4x25.4	13.0	5.9	190.0 ¹	47.5
S-band						14.5
Ku-band						7.0
Antenna, incl. support strut			33.96	15.4	24.0	
MDR NO. 2						
Receiver	12x8x4	30.5x20.4x10.2	8.8	4.0		6.2
Transmitter	6x3.75x10	15.3x9.5x25.4	11.0	5.0	180.4 ¹	45.1
S-band						13.2
Ku-band						7.0
Antenna, incl. support strut			33.96	15.4	24.0	
TDRS/GS						
Receiver	9x5x4	22.9x12.7x10.2	4.7	2.14		5.25
Transmitter	7x6.5x4	17.8x16.5x10.2	6.0	2.73	49.0 ²	11.0
Antenna			14.85	6.75	9.5	
FREQUENCY SOURCE	10x10x2	25.4x25.4x5.1	5.6	2.5		4.8
TT&C						
Processor	6.2x4.5x5.4	15.7x11.4x13.7	9.6	4.4	10.0	10.0
Transceiver	5.5x5.5x2.63	14x14x6.7	4.0	1.8	4.5 ³	0.5
Antenna			3.0	1.36		
TDRS TRACK'G/ORDER WIRE						
Transponder	8x4x0.5	20.3x10.2x1.3	5.4	2.5		7.9
Antenna			0.3	0.1		
KU-BAND BEACON						
Beacon	4x3x3	10.2x7.62x7.62	3.6	1.6		8.3
Antenna			0.3	0.1		
DC CABLING			13.3	6.04		
RF CABLING	75 feet	(22.9 meters)	4.9	2.2		
WAVEGUIDE			5.0	2.3		
Totals			240.17	109.4		
Two MDR's in S-band						256.0
One MDR in Ku-band, one in S-band						224.1
Two MDR's in Ku-band						191.1
NOTES						
1 For voice operation						
2 During rain at ground station, add 10 dB to transmitter power						
3 Transmitter (4 watts) not used "on station"						

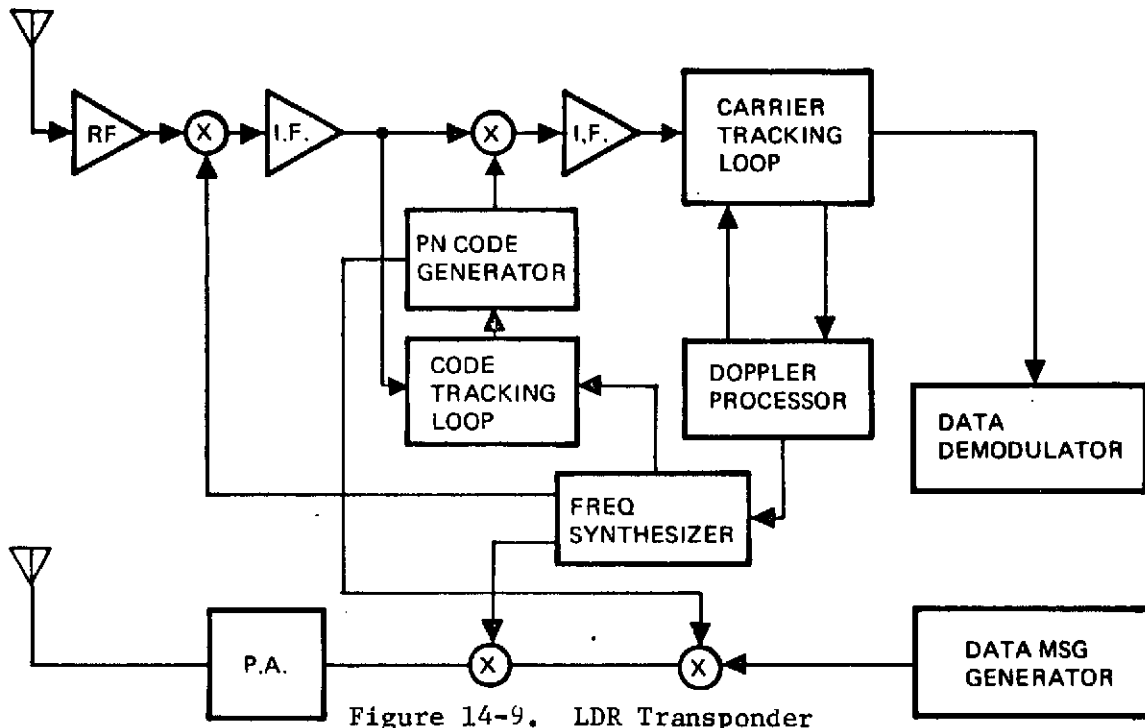


Figure 14-9. LDR Transponder

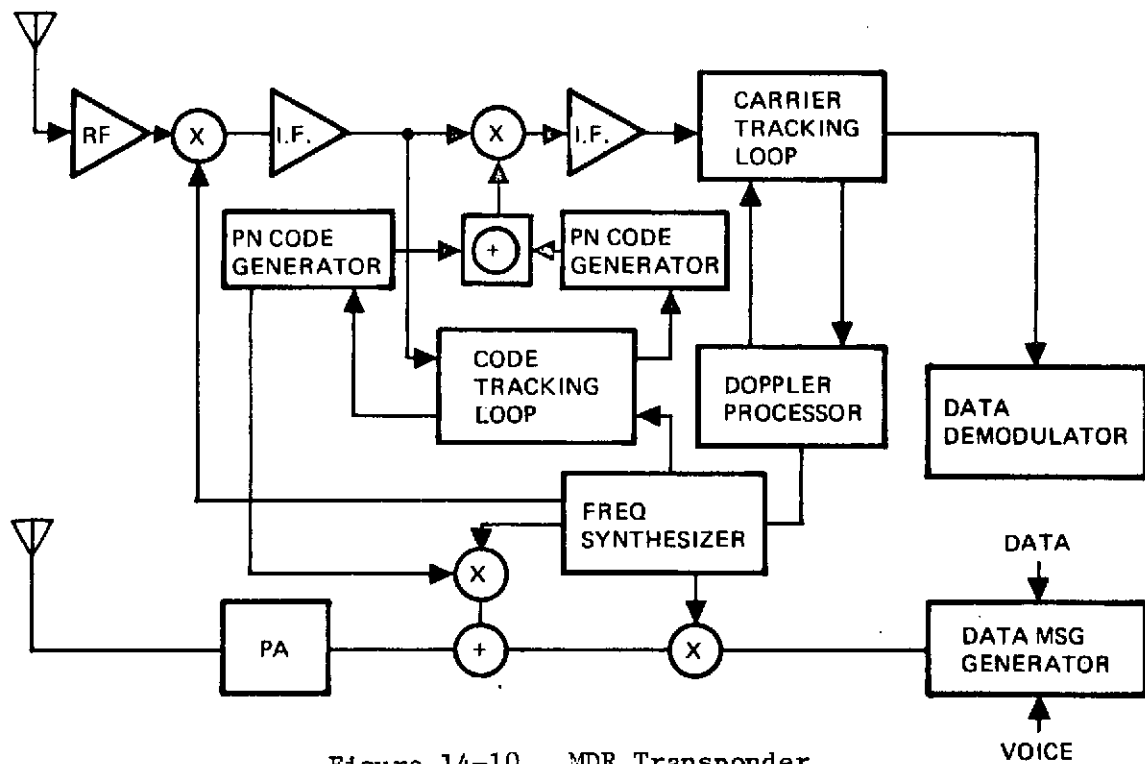


Figure 14-10. MDR Transponder

Return Link

- Data Rate 100 bps to 10,000 bps
- Carrier Frequency 136 MHz (1 channel)
- PN Modulation 1 mchip/sec
- Code Length Short - 2047 chips (gold sequence)
Long - Sixty-six 2047 (gold sequences in serial)
- Unique Code Sequence For Each User (TDRS Access is CDMA)
- The 167 Kchip/sec PN chip rate in the forward link is necessary to distribute the signal energy to conform to IRAC requirements.
- A short PN code is used during the code acquisition phase to limit the maximum acquisition time to 40 sec.
- A long code is switched in after code acquisition to provide unambiguous ranging over a two-way range uncertainty of 40,000 Km.
- A 1 Mchip/sec PN chip rate in the return link is necessary to provide multiple access of 20 users per TDRS with sufficient process gain to meet the required level of performance.
- The return link code configuration is designed to maintain code synchronization with operating at different data rates.

14.4.2.2 MDR Transponder on User S/C

The MDR terminal receiver is a single channel S-band receiver. The carrier in the forward link is modulated by a single 5 Mchip/sec PN sequence during the code acquisition phase to distribute the signal energy radiated from the TDRS to conform to IRAC requirements. During the ranging phase a second PN sequence of 500 Kchip/sec rate is module-2 added to the first. A 500-Kchip/sec PN code generator synchronized to the uplink 500-Kchip/sec code is used to modulate the downlink carrier.

In both manned and unmanned users the data is delta PSK with convolutional encoding for error control. In the manned user case, the data and delta modulated voice can be time division multiplexed to quadrature phase multiplexed to form a serial data stream. A simplified schematic diagram of the MDR transponder is shown in Figure 14-10.

A preliminary estimate of the size and prime power requirements for the user MDR transmitter and receiver are: transmitter - power, 33 watts; size, 240 in³ (4000cc) and receiver - power, 12 watts, size 205 in³ (3400cc).

The following is a summary of the characteristics of the MDRU terminal.

MDR User Terminal Characteristics

Forward link

- . Data rate⁽¹⁾ 100 bps to 1000 bps
- . Carrier frequency⁽¹⁾ 2025 to 2120 MHz (2 channels)
- . PN modulation 5M chips/sec
- . Code length Short: 16,383 chips (gold sequence)
Long: Forty 16,383 gold sequences in serial
- . PN code sequence common to both users
- . Ranging code Rate: 500 Kchips/sec; length: 65,535 chips

Return link

- . Data rate⁽¹⁾ 10 kbps to 1000 kbps
- . Carrier frequency⁽¹⁾ 2200 to 2300 MHz
- . PN modulation is transponded 500 Kchip/sec
PN modulation
- . Unique frequency channel for each of 2 users

(1) Ku-band service operates at a carrier frequency of 14.6 to 15.2 and 13.6 to 14.0 GHz for the forward and return link, respectively; the forward link PN chip rate is on the order of 50 Mcps and the return link data rate is in excess of 1 Mbps.

- . A 5 Mchip/sec PN chip rate in the forward link is required to distribute the signal energy to conform to the IRAC requirements.
- . A short code is used during the code acquisition phase to limit the maximum acquisition time to 33 sec.
- . A long code is switched in after code acquisition to provide unambiguous ranging over a two-way range uncertainty of 40,000 Km.
- . The ranging code is used to limit the code for ranging purposes while still providing enough resolution to derive the required accuracy.
- . A 65,535 code length is necessary to provide ambiguous ranging.
- . The PN modulation in the return link is the 500 Kchip/sec PN code which can be transponded in the user for ranging purposes only.

14.4.3 Ground Station Terminal Characteristics

A functional block diagram of the TDRS Ground Station is shown in Figure 14-11. The components of the ground station telecommunication equipments are: RF front end, AGIPA processor, demodulator/tracking unit, and modulator. Its major characteristics are summarized in Table 14-13.

Table 4-13. Ground Station Telecommunications Characteristics

RF Front End	
• Antenna (2)	• 60 Feet (18.3m) parabolic dish, 75% efficient with >70 dB front-to-back ratio
• Receiver (2)	• 600 MHz front end with paramp ($T_e = 100$ K) • Demux - 40 LDR user; 4 MDR users, 2 Tracking and Telemetry, and 2 order wire
• Transmitter (2)	• Mux - 2 LDR, 2 MDR, TDRS Command, pilot • Transmit Power = 60 watts/TDRS
AGIPA Processor	• 1 processor/LDR user including a mini-computer for each processor • Uses PN Code to separate desired from interference signal • Uses adaptive spatial and polarization information to filter interference signals
Demodulator/Tracking Unit	• Extract NRZ-L bit stream from PN- Δ PSK input • Search and synchronize to desired PN code • Extract desired telemetry data • Extract range data
Modulator	• Convert NRZ-L data stream to Δ coded PCM, PN coded • Bi-phase modulate onto appropriate sub-carrier • Provide start pulse for the receiver tracking circuit

Page intentionally left blank